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## Fokker-Planck Modelling Of Edge Plasma Near The Neutralizer Plate In A Tokamak

Z. Abou-Assaleh\*, J.P. Matte, T.W. Johnston and R. Marchand  
INRS-Energie, C.P. 1020, Varennes, Quebec, Canada J3X 1S2

An electron kinetic code (FPI)<sup>+</sup> is modified and used to simulate longitudinal transport and recycling near the neutralizer plate in a divertor plasma. In addition to the previous features, such as Fokker-Planck e-e and e-i Coulomb collisions, transport, ion motion, and a self-consistent electric field, the code now accounts for ionization, excitation, and recycling of hydrogen near the plate. Ions and neutrals are treated as fluids. As one might expect, this full FPI code is very expensive to run, having fast (electron) and slow (ion motion) timescales. We therefore use this FPI code in conjunction with a two-fluid ambipolar code, whose electron heat flow is obtained from usual flux limited coefficients on thermal transport. We alternate the codes, using the FPI code to correct the fluid code's temperature and local heat transport, while using the fluid code for ion dynamics. We thus arrive at an equilibrium consistent with electron kinetics but at a tiny fraction of the cost of doing so with the FPI code alone. Results and applications will be discussed.

\* Present address: Culham Laboratory, D2, Abingdon, Oxfordshire, UK

+ J.P. Matte and J. Virmont, Phys. Rev. Lett. 49, 1936 (1982); J.P. Matte, T.W. Johnston, J. Delettrez and R.L. McCrory, Phys. Rev. Lett. 53, 1461 (1984); J.H. Rogers, J.S. De Groot, Z. Abou-Assaleh, J.P. Matte, T.W. Johnston and M.D. Rosen, Phys. Fluids B1, 1989.

# INTRODUCTION

## **Aim:**

Modelling of the divertor plasma in a tokamak  
(Particles and energy transport along the magnetic  
field line)

## **Methods:**

Electron kinetic / ion fluid code (FPI)

1D and 2-fluid code

Iteration FPI code ↔ modified fluid code

# FOKKER-PLANCK INTERNATIONAL CODE FPI

- \* Electrons are treated kinetically
- \* Ions and neutrals are treated as fluids.
- \* 1-D in space (x) and 2-D in velocity space ( $v_x$ ,  $v_\perp$ ).
- \* The electron distribution function is:

$$f(X, V, t) = f(x, v_x, v_\perp, t) = f(x, v, \mu, t) = \sum_{l=0}^N f_l(x, v, t) P_l(\mu)$$

where  $v = (v_x^2 + v_\perp^2)^{1/2}$ ,  $\mu = v_x/v$  and  $P_l(\mu)$  is the  $l$ th Legendre polynomial. We have used  $N=3$  in the simulations.

- \* The kinetic equation for the electron is given by :

$$\frac{\partial f}{\partial t} + v_x \frac{\partial f}{\partial x} + \frac{eE}{m_e} \frac{\partial f}{\partial v_x} = \left( \frac{\partial f}{\partial t} \right)_{(e-i, e-e)} + \left( \frac{\partial f}{\partial t} \right)_{(E_d)} + \left( \frac{\partial f}{\partial t} \right)_{(e-n)}$$

- The second and third terms in the left hand side are the advection and the acceleration due to the electric field, respectively.
- The right-hand side terms represent respectively electron-ion, electron-electron, Coulomb scattering, electron-ion energy exchange and electron-neutral collisions.
- \*  $f_l$ 's are advanced in time.

# FLUID CODE

The code solves for a single density, single velocity and two temperatures as a function of time. The following equations are advanced in time:

**Continuity:**

$$\frac{\partial}{\partial t} n + \frac{\partial}{\partial x} (nv) = S_n$$

**Momentum balance:**

$$\frac{\partial}{\partial t} (m_i nv) + \frac{\partial}{\partial x} \left( m_i nv^2 + P_e + P_i - \frac{4}{3} \eta \frac{\partial v}{\partial x} \right) = S_p$$

**Electron energy balance:**

$$\frac{\partial}{\partial t} \left( \frac{3}{2} n T_e \right) + \frac{\partial}{\partial x} Q_e = v \frac{\partial}{\partial x} P_e + E_{ei} + S_e$$

**Ion energy balance:**

$$\frac{\partial}{\partial t} \left( \frac{3}{2} n T_i + \frac{1}{2} m_i nv^2 \right) + \frac{\partial}{\partial x} \left( Q_i - \frac{4}{3} \eta v \frac{\partial v}{\partial x} \right) = -v \frac{\partial}{\partial x} P_e - E_{ei} + S_i$$

With:

$$q_e = q_{SH} \left[ 1 + \frac{|q_{SH}|}{f n_e v_e T_e} \right]^{-1}$$

f = 0.2 (Electron heat flux limit factor)

# BOUNDARY CONDITIONS

## FPI CODE

### PLASMA SOURCE ( $x = 0$ ):

Ions:  $n_i$ ,  $V_i$  and  $T_i$  are fixed.

Electrons:  $T_e$  fixed. Zero current ( $\Gamma_e = \Gamma_i$ ) is imposed as follows: incoming particles are absorbed and an appropriate current with half-Maxwellian distribution at this temperature is emitted.

### PLATE SHEATH EDGE ( $x = L$ ):

Ions: Outgoing ions are absorbed by the plate.

Electrons: Zero current ( $\Gamma_e = \Gamma_i$ ) is imposed as follows: low energy electrons ( $< m_e V_r^2 / 2$ ) are reflected so that the flux of higher energy electrons is equal to the ionic current.

## FLUID CODE

### PLASMA SOURCE ( $x = 0$ ):

$n = n_{e,i}$ ,  $V = V_{e,i}$ ,  $T_e$  and  $T_i$  are fixed.

### PLATE SHEATH EDGE ( $X = L$ ):

- The outgoing plasma is absorbed.
- Ion drift velocity :  $V \geq C_s = \sqrt{(T_e + T_i) / m_i}$
- Heat flux:  $Q_i = 3.5 n V T_i$ ,  $Q_e = 2 \delta n V T_e$ , ( $\delta = 3$ )

# FLUID AND FOKKER-PLANCK HYBRID ITERATION

## FLUID CODE

Moves ions ect. quickly, but electron heat flow is approximate.

## FOKKER-PLANCK (FPI) CODE

Some ion dynamics but with electron kinetics, too slow on ion timescale.

## SOLUTION

Iterate fluid modified by FPI

Use  $T_e(\text{FPI})$  and force  $q_e$  to agree with FPI by correcting each grid point with correction factors:

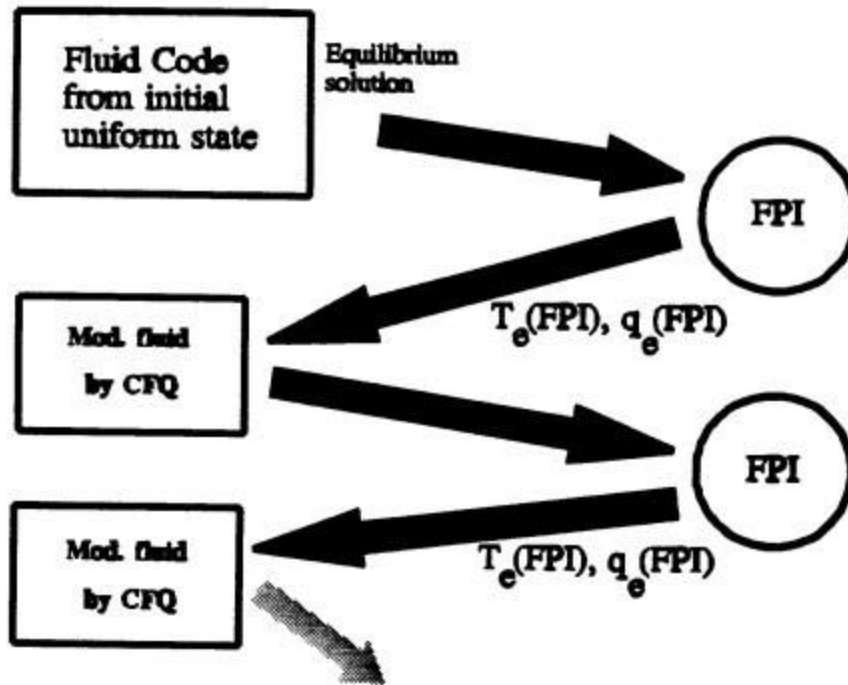
$$\text{CFQ} = q_{e\text{-FPI}} / q_{e\text{-fluid}}(T_{e\text{-FPI}})$$

ITERATE UNTIL NO FURTHER  
SIGNIFICANT CHANGE

## FINAL RESULT

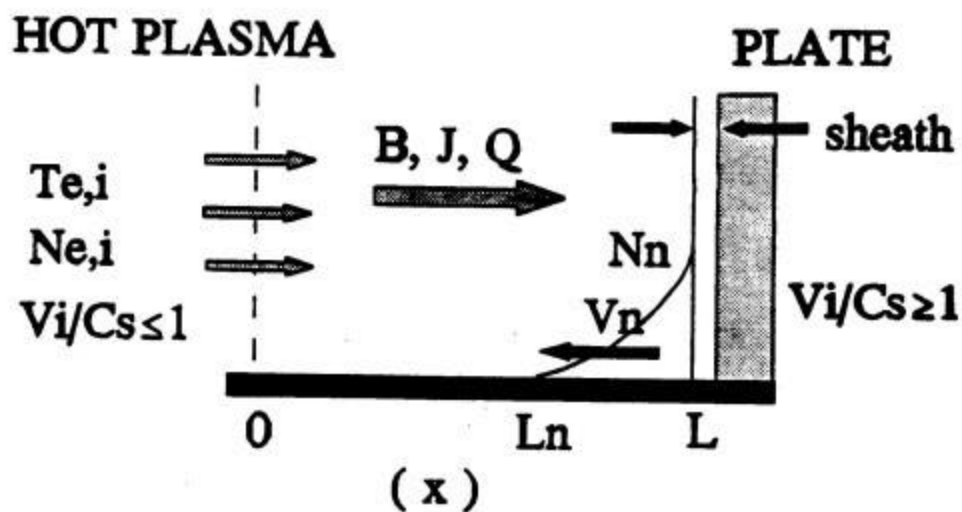
Profile consistent with electron kinetic  
but at affordable cost.

# FLUID AND FOKKER-PLANCK HYBRID ITERATION



$$CFQ = \frac{q_{e-FPI}}{q_{e-fluid}(T_{e-FPI})}$$

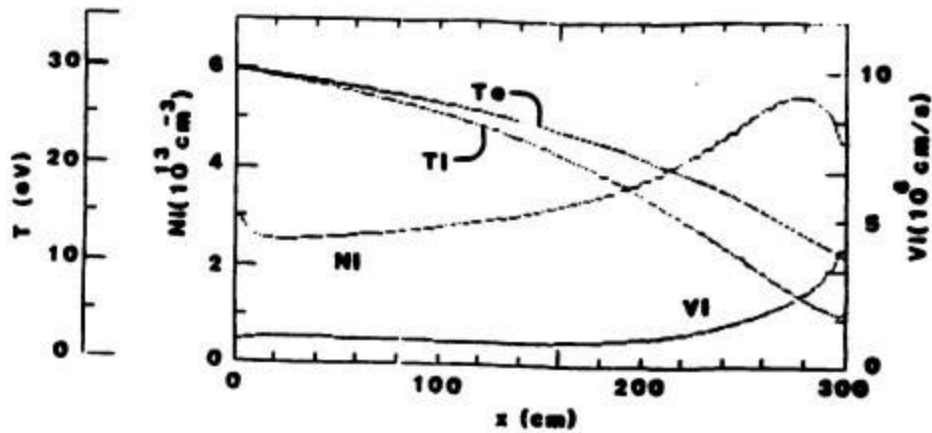
# DIVERTOR PLASMA SIMULATIONS WITH HIGH RECYCLING



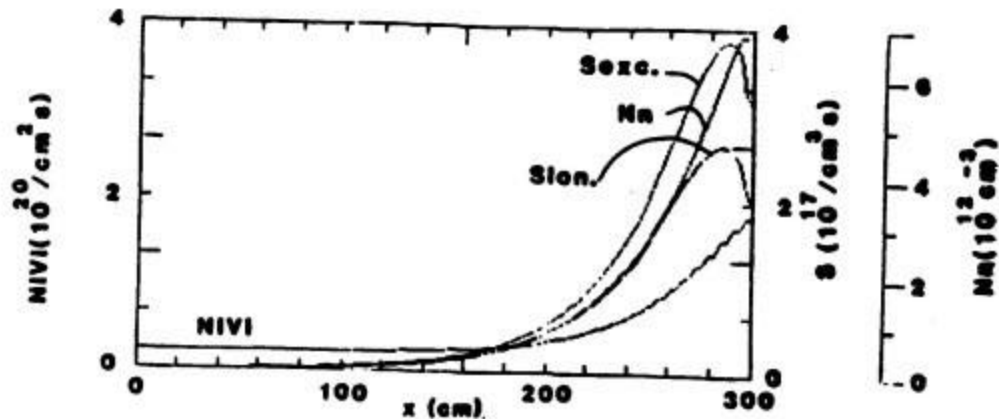
$$\begin{aligned}
 L &= 300 \text{ cm} \\
 T_{e0} &= T_{i0} = 30 \text{ eV} \\
 n_{e0} &= n_{i0} = 3 \times 10^{13} \text{ cm}^{-3} \\
 m_n V_n^2 / 2 &= 3 \text{ eV} \\
 n_n V_n &= 0.8 n_i V_i \text{ at } x=L \\
 m_i / m_e &= 1836
 \end{aligned}$$

# FLUID CODE SIMULATION

$T_e$ ,  $T_i$ ,  $V_i$  and  $n_i$  vs  $x$

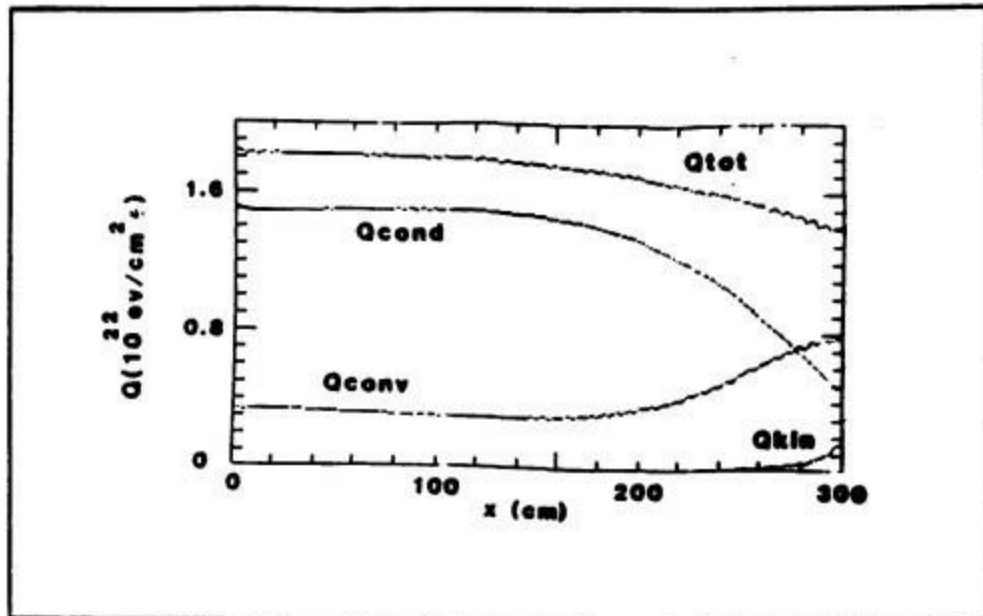


$n_i V_i$ ,  $n_n$ ,  $S_{exc}$  and  $S_{ion}$  vs  $x$

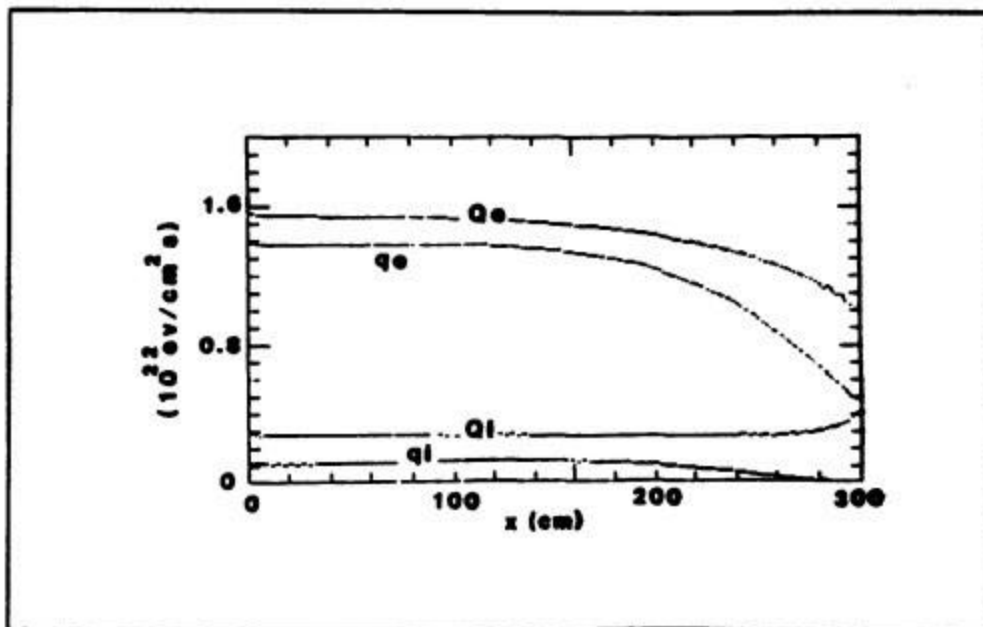


# FLUID CODE SIMULATION

## Energy flux



Fluid equilibrium solution of edge plasma near the plate with high recycling: Profiles of  $Q_{\text{tot}}$ ,  $Q_{\text{cond}}$ ,  $Q_{\text{conv}}$ , and  $Q_{\text{le}}$ .

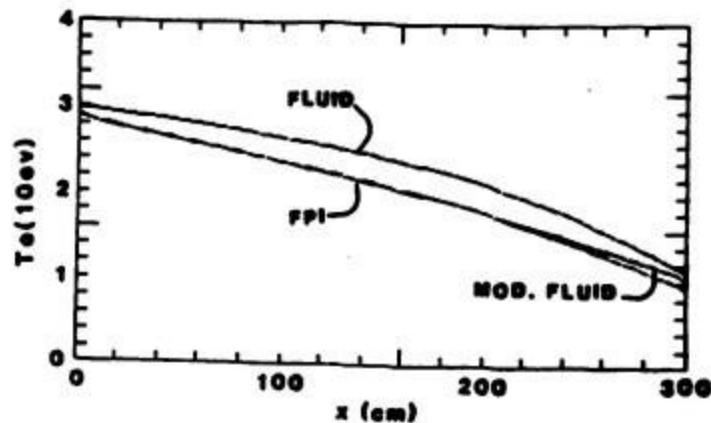


Fluid equilibrium solution of edge plasma near the plate with high recycling: Profiles of  $Q_e$ ,  $q_c$ ,  $Q_i$ , and  $q_l$ .

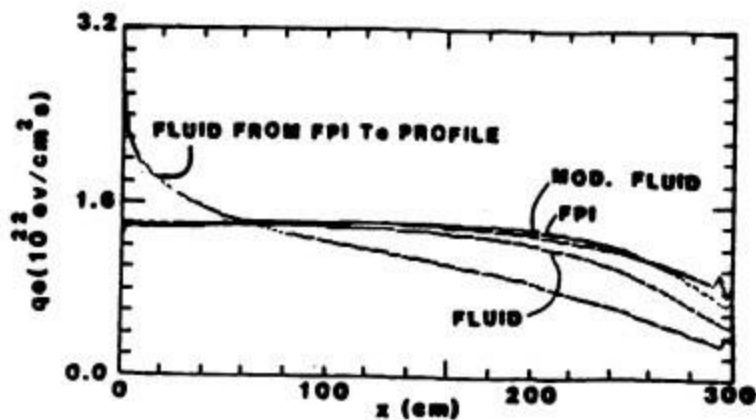
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# FLUID AND FOKKER-PLANCK HYBRID SIMULATION

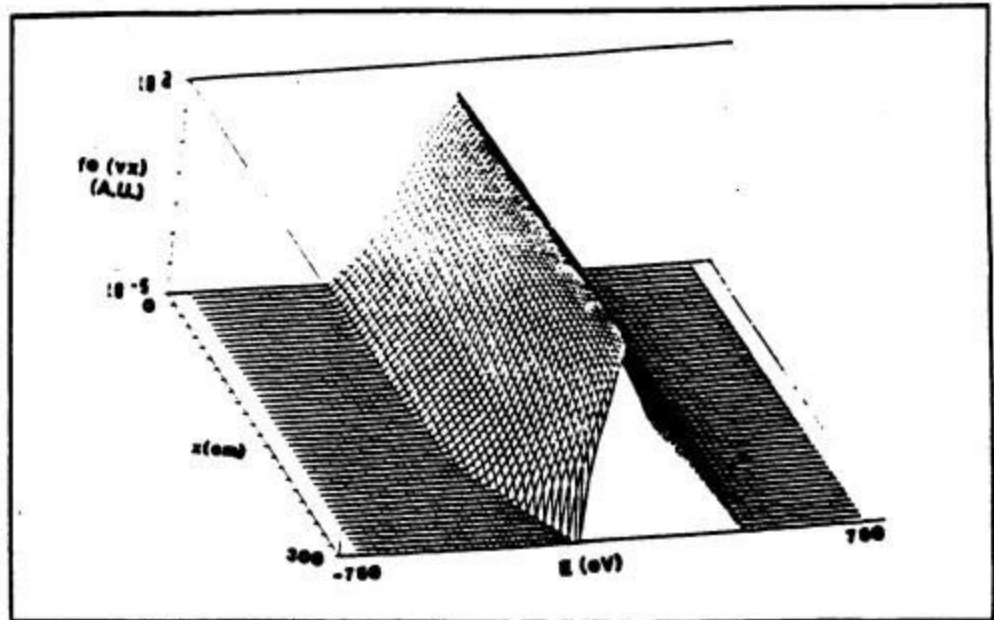
Profile of  $T_e$   
Fluid ( $f=0.2$ ), FPI and Mod. Fluid



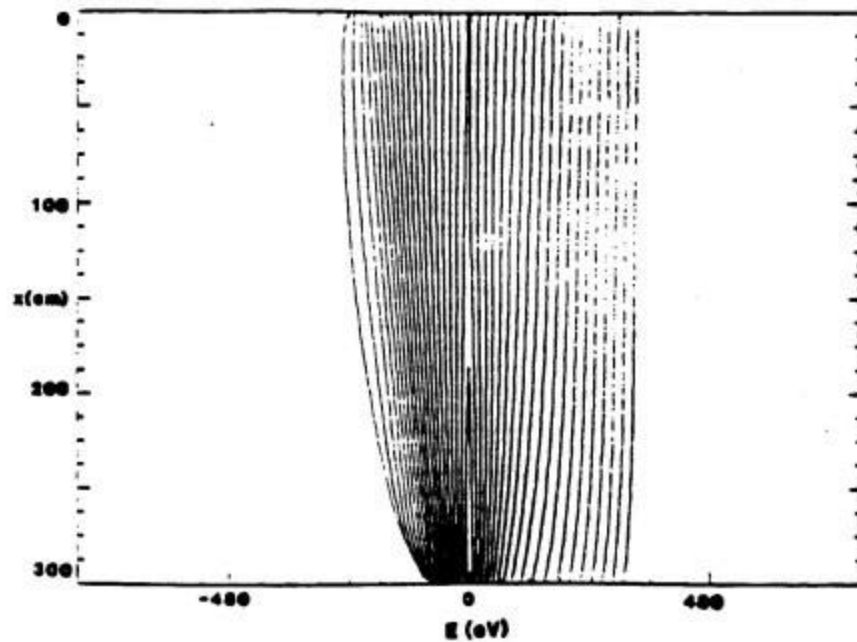
Profile of  $q_e$   
Fluid ( $f=0.2$ ), FPI and Mod. Fluid



# ELECTRON DISTRIBUTION FUNCTION CALCULATED BY FOKKER-PLANCK CODE



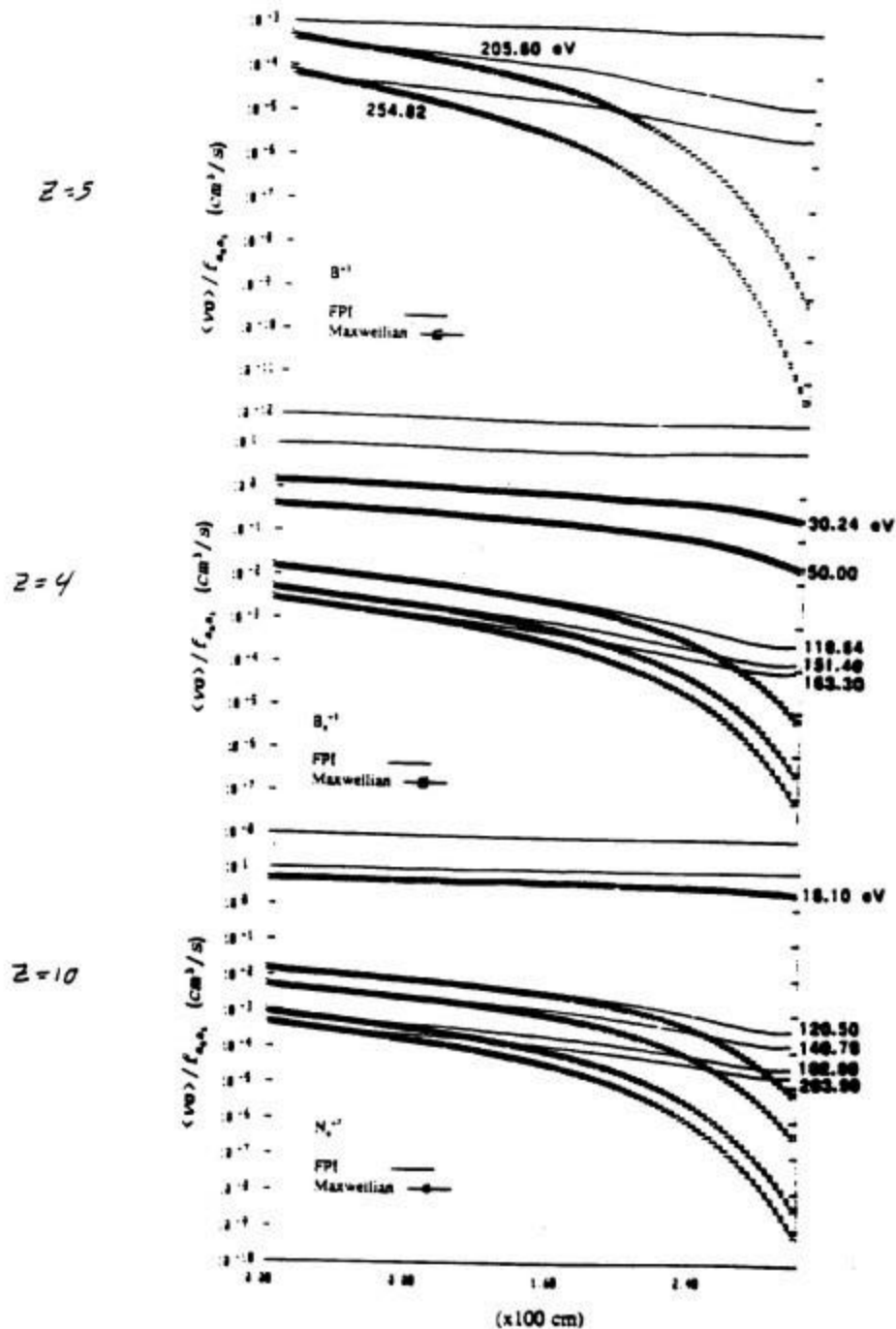
Fokker-Planck calculation:  $f_e(v_x)$  vs  $x$  and sign  $E=1/2m_e v_x^2$



Fokker-Planck calculation: the contour lines of  $f_e(v_x)$  vs  $x$  and sign  $E=1/2m_e v_x^2$ . The truncation of  $f_e(v_x)$  at the plate is clearly seen from this figure.

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# NON-MAXWELLIAN ELECTRON DISTRIBUTION EFFECT ON THE IMPURITIES RADIATIONS



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# CONCLUSION

We model the plasma transport along the magnetic field line in a tokamak divertor:

- \* Fluid and kinetic simulations.
- \* Including: ionization, excitation, boundary condition at the sheath edge.
- \* Hybrid technique was developed which produced an equilibrium solution with the electron kinetic model but with much reduced computer cost.
- \* Steep temperature gradients.
- \* The fluid code with electron heat flux limiter  $f=0.2$  gave closer results to the Fokker-Planck calculation.
- \* The electron distribution function calculated from the FPI code is not locally Maxwellian, especially near the plate. The deviation from Maxwellian is due to the absorption of the most energetic electrons by the plate and to the non-local transport of high energy electrons.
- \* Effect of non-Maxwellian electron distribution function on the ionization and excitation of the impurities.